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# ***CICT/Intelligent Systems Project***

## ***MTP Briefing***

***Dr. Butler Hine***  
***IS Project Manager***

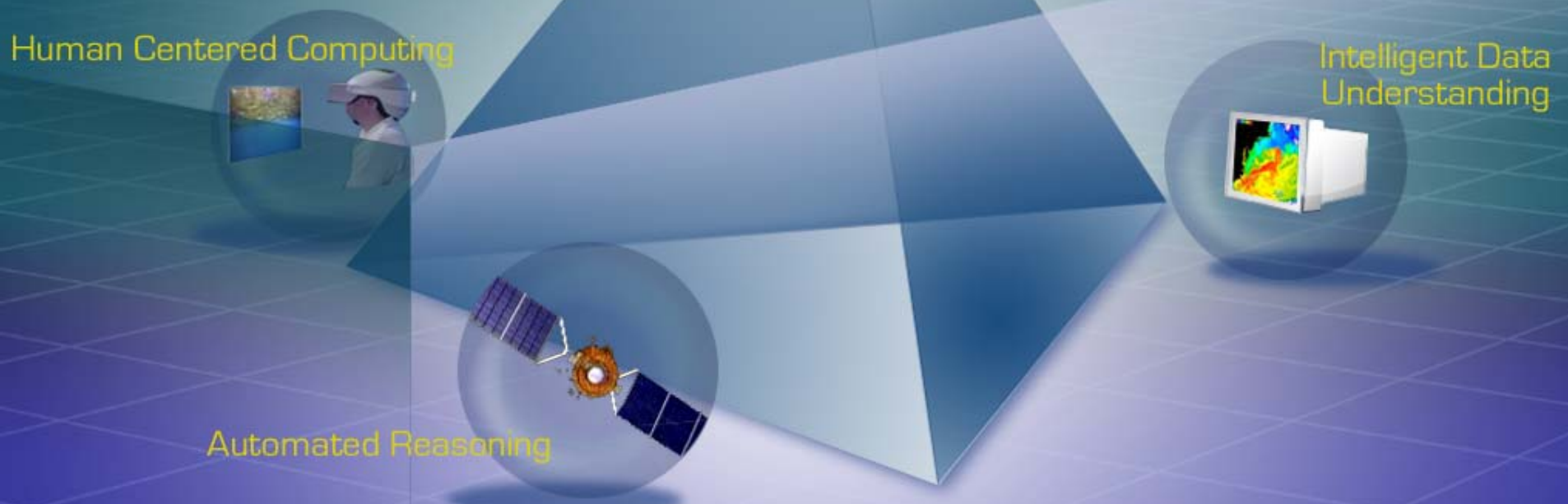
***Butler.P.Hine@nasa.gov***





# ***Intelligent Systems***

***Goal: Strategic research to enable smarter, more adaptive systems and tools that work collaboratively with humans in a goal-directed manner to achieve the mission/science goals.***



# NASA Enterprise Requirements Areas



Level-3 Area	Aero/Space Transportation	Earth Science	Space Science	Human Exploration	Biological and Physical Research
Automated Reasoning	On-board vehicle health management methodologies	Multiple satellite/instrument control and formation flying	New generation of autonomous science rovers and spacecraft		Remote Science Experiment Capability
Intelligent Data Understanding		Distributed database discovery methods; methods to establish causality		Methods to integrate vehicle databases to establish causal relationships for safety of operation	
Human-Centered Computing	Mixed-initiative system methodologies to enhance aviation system capacity			Mixed initiative system methodologies to reduce mission operations costs	Automated operation and monitoring of Human Support Systems for crewed missions



# Automated Reasoning



## Project Goal:

**“Develop technology designed to automate and augment the human decision making process with a focus on higher-level, cognitive tasks that are traditionally performed by humans.”**

### Technology Development

- Autonomy Architectures and Smart Executives
- Planning and Scheduling
- Hybrid Diagnosis
- Autonomy Software Generation and Assurance



### Capabilities

- Automated generation of command sequences
- Automated generation of state estimation code

2002

2004

- Autonomy Architectures and Smart Executives
- Planning and Scheduling
- Hybrid Diagnosis
- Autonomy Software Generation and Assurance



- Unified flight/ground autonomy architecture
- Goal-driven commanding

2007

20XX

- Autonomy Architectures and Smart Executives
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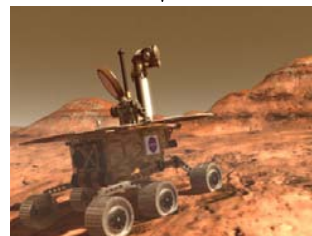


- Automated generation and testing of flight software
- Science-directed agents in dynamic environments

20XX

20XX

### Applications/ Missions



**Improvement  
in Science Return**



**Mission  
Enabling**



**Mission  
Enabling**

### Target Impact



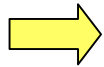
# Intelligent Systems Automated Reasoning



## Investment Areas (with selected tasks):

- **Autonomy Architectures and Smart Executives**

- > Intelligent Distributed Execution Agent (IDEA) unified autonomy architecture (Directed, Muscettola ARC)
- > On-board rover autonomy architecture (Directed, Washington ARC, Volpe JPL)



- **Planning and Scheduling**

- > SOFIA Automated Observation Scheduling (Directed, Frank ARC)
- > Using Combinatorial Optimization Algorithms to Improve Automated Planning and Scheduling (NRA, Smith JPL)
- > Multi-Resolution Planning in Large Uncertain Environments (NRA, Kaebling MIT)

- **Hybrid Diagnosis**

- > Non-parametric hybrid fault detection (Directed, Dearden ARC)
- > A Hybrid Discrete/Continuous System for Health Management and Control (NRA, Williams MIT)
- > Probabilistic Reasoning for Complex Dynamic Systems (NRA, Pfeiffer Harvard)
- > Robust Methods for Autonomous Fault-Adaptive Control of Complex Systems (NRA, Biswas Vanderbilt)

- **Robotics**



- > An Onboard Scientist for Multi-Rover Scientific Exploration (NRA, Estlin JPL)
- > Heterogenous Multi-rover Coordination for Planetary Exploration (NRA, Simmons CMU)

- **Autonomy Software Generation and Assurance**

- > System-level verification for autonomy (Directed, Lowry ARC)
- > Formal Verification Tools and Techniques for Autonomous Systems (NRA, Wing CMU)

- **Distributed Autonomy**

- > Continual Coherent Team Planning (NRA, Barret JPL)



# On-board Rover Autonomy Architecture



## Demonstrated infrastructure for integrating robotic and autonomy technologies for long-range traverse of rovers

**Shown:** An architecture for integrating autonomous decision-making capabilities with functional control layer for rovers.

**Decision Layer:** Robust, dynamic autonomous replanning, path-planning, and execution. Planner and executive share information, collaborate on decisions

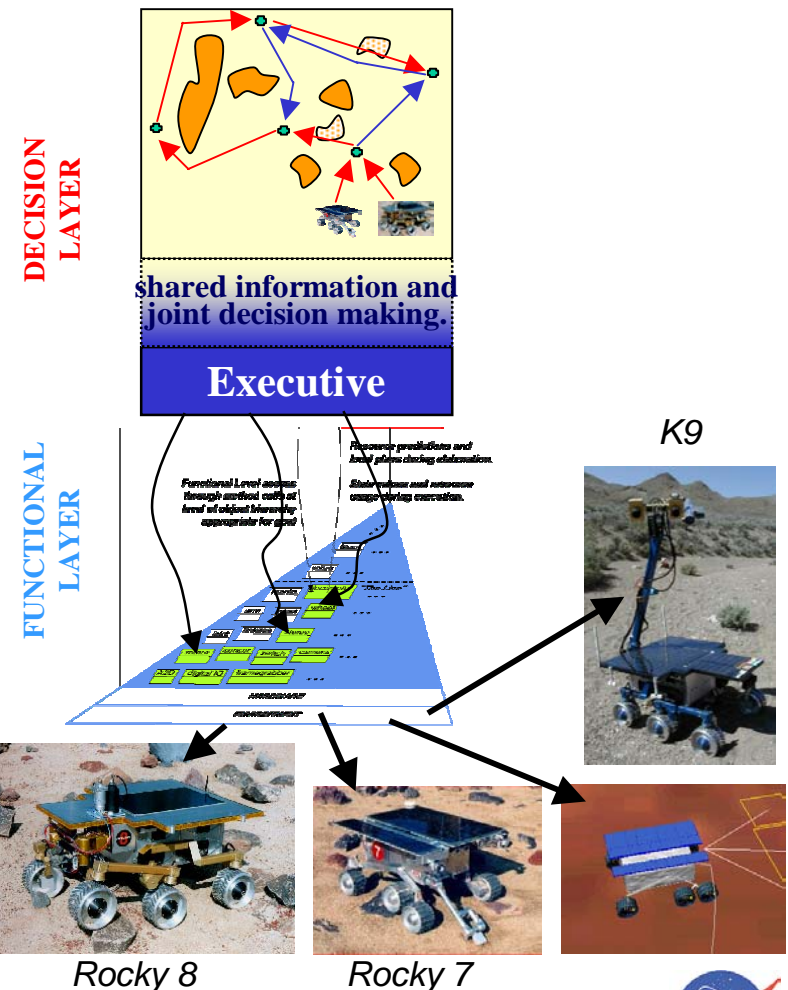
**Functional Layer:** Low-level autonomy capabilities such as locomotion, manipulation, and vision-based navigation. Generalized, reusable framework supports multiple platforms, including Rocky 7&8, K9, and Roams simulator.

**Demonstrated on long range rover traverse scenarios:** Rapid response, replanning based on unexpected events, including unexpected obstacles in path, and delays in accomplishing science goals.

**Beneficiaries:** Code S, MSL

**Output:** A novel system that combines planning and execution technology for command-sequence generation and re-planning to provide a quick, intelligent response to unexpected situations. To generate high-quality rover schedules, several pieces of knowledge are incorporated, including spatial and route information, resource constraints, and rover site knowledge.

**Outcome:** An integrated hardware/software system for autonomous Mars surface exploration.







# MISUS: Multi-Rover Integrated Science Understanding System



**Goal:** Provide an “onboard scientist” capability to a team of rovers. Enable the team to investigate a new environment in a closed-loop, autonomous fashion with little communication from ground.

## Objectives:

- Integrate AI machine learning and planning techniques to provide closed-loop data collection, analysis and sequence generation.
- Intelligently coordinate multiple rovers in performing science operations both at command level and science analysis level.

## Key Innovations:

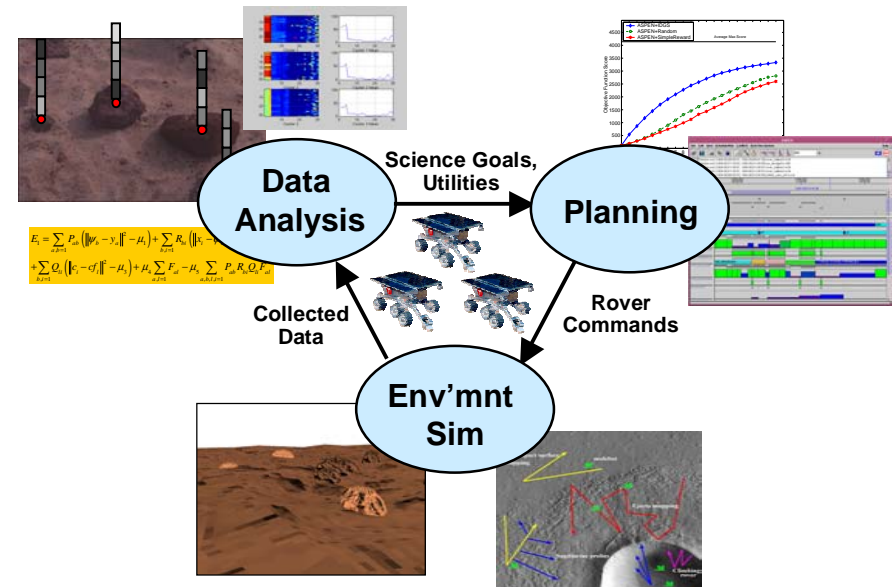
- Develop strategies for interdependent science-goal selection and successful achievement
- Enable continuous science, where new data is iteratively analyzed and changing science objectives are reflected in team schedule

## NASA Relevance:

- Enabling to future missions that utilize larger and smarter sets of rovers to gather science data.
- Also applicable to spacecraft and/or constellation missions that would benefit from onboard data analysis

## Accomplishments to date:

- Developed new data analysis algorithm for evaluating measurement uncertainty and science goal relationships
- Developed planning optimization approach for handling interdependent science-goal utilities
- Developed distributed planning capability for re-assigning science goals due to unexpected failures
- Extended environment simulation to incorporate more realistic mineralogical distribution



## System Description:

- **Data Analysis:** A machine-learning system that analyzes input visual and spectral data, and prioritizes new science targets.
- **Planning:** A distributed, continuous planning system that produces rover operation plans to achieve input science goals.
- **Environment Simulation:** A multi-rover simulator that models geological environments and rover science activities within them.

## Schedule:

- FY01: Develop centralized scheduling of interdependent subgoals. Develop analysis algorithm for evaluating goal relationships.
- FY02: Develop distributed scheduling of interdependent science goals. Implement analysis algorithm. Integrate rock-patch-facies-deposit terrain model.
- FY03: Enable continuous science goal evaluation and integration into rover schedule. Evaluate full system on field data.

# Technology infusion for MER: MAPGEN



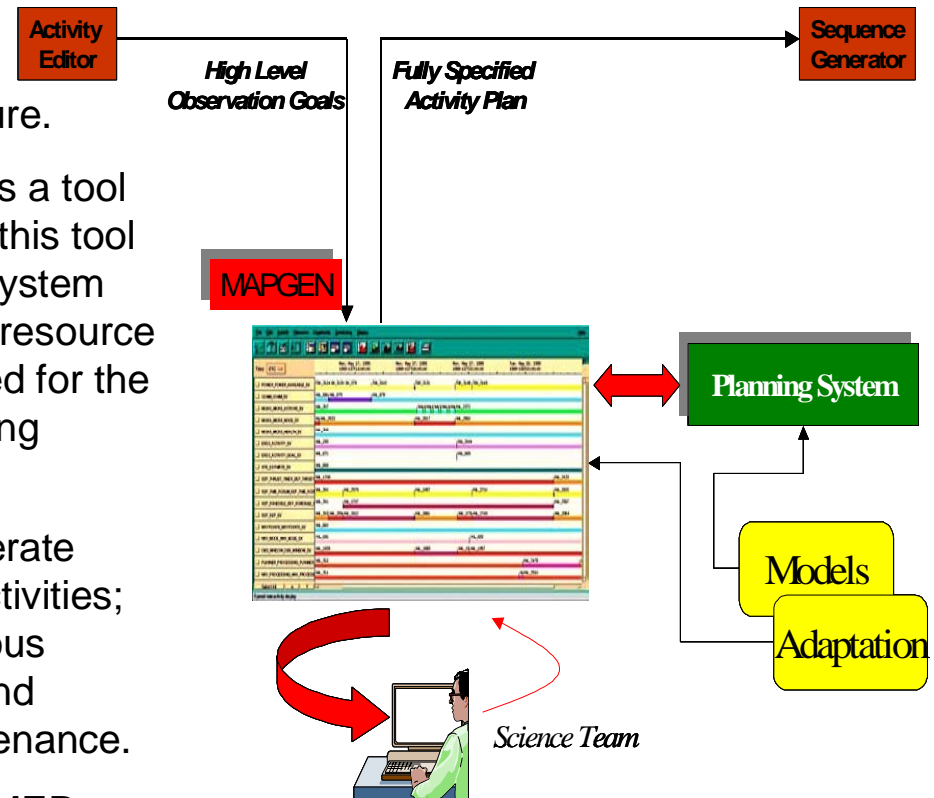
**Shown:** MAPGEN MER Science Planning Architecture.

MAPGEN (Mixed-Initiative Activity Plan GENERator) is a tool for Science Activity Planning. The primary users of this tool are to be MER mission scientists who will use the system for planning and scheduling activities within known resource bounds. MAPGEN in the Planner mode is base-lined for the Science Operations Working Group (SOWG) meeting during the daily tactical build of the uplink process.

**Output:** MAPGEN will be used to automatically generate plans and schedules of science and engineering activities; in hypothesis testing using what-if analysis for various scenarios; for plan editing; resource computation and analysis; and for constraint enforcement and maintenance.

**Outcome:** Improved efficiency and effectiveness of MER ground operations teams.

**Beneficiaries:** MER Project

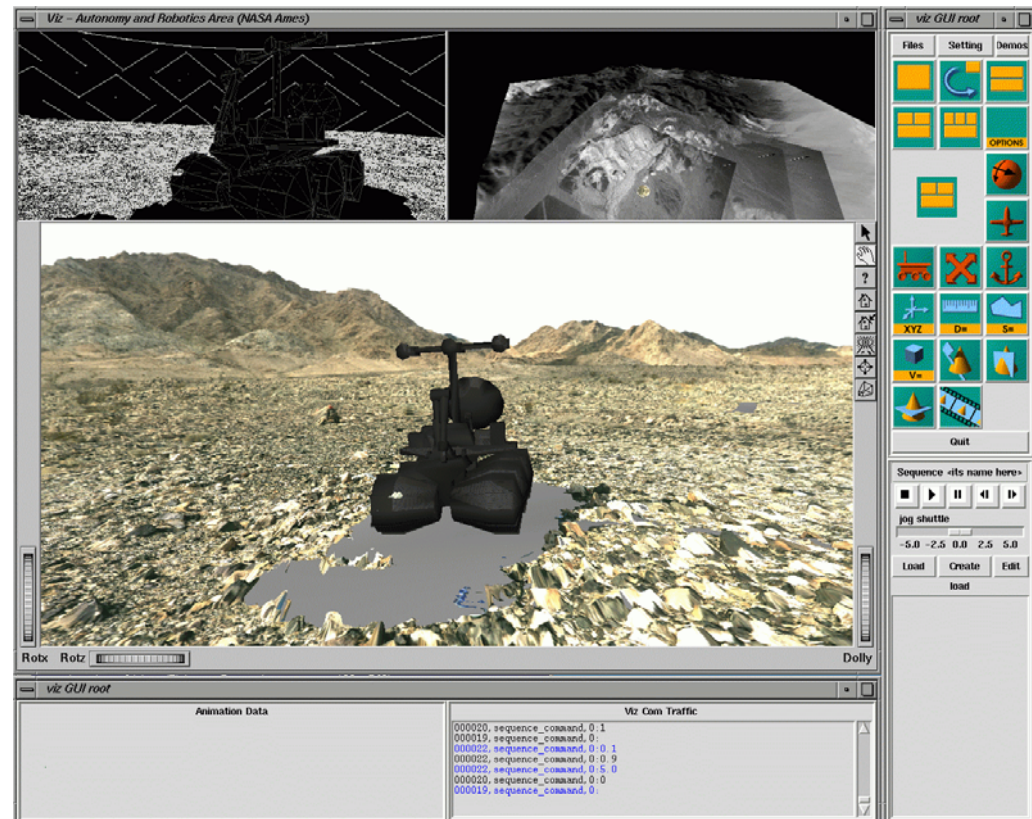




# VIZ: High-performance integrated data visualization for science planning



**Shown:** In a field experiment in the Mojave desert hundreds of stereo images were downlinked and integrated into 3D terrain models. The image shows how we integrated the local dataset (in color) into a larger digital elevation map (DEM) from USGS (upper right view).



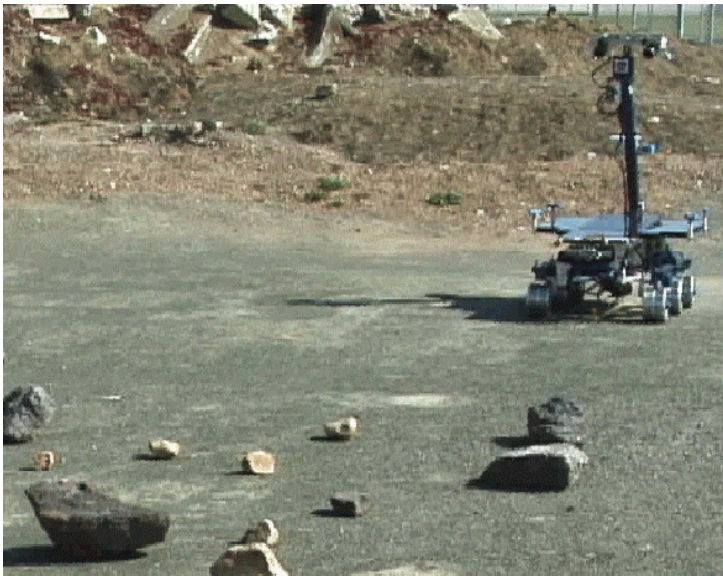
**Output:** Mission-tested state-of-the-art tool for remote visualization and terrain modeling.

**Outcome:** Improved science planning and potential support for advanced distributed operations for future remote exploration missions.

**Beneficiaries:** Pathfinder; MER; MSL



# Rover Autonomous Instrument Placement



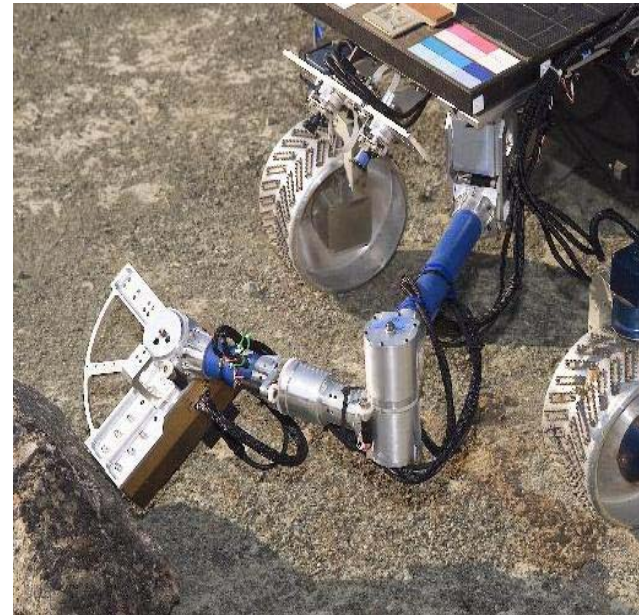
*Navigation:*  
Visually track science  
target with multiple  
stereo cameras



*Hand-off*  
target from  
navigation  
cameras to  
close-up  
cameras

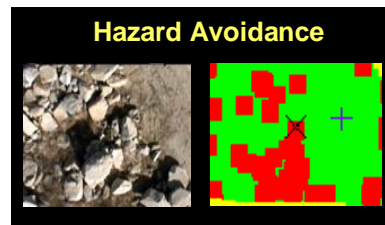
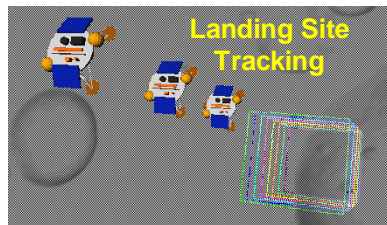


*Instrument Placement:*  
Find target  
Find suitable area for  
placing sensor





# Autonomous Vision Guided Safe and Precise Landing



## TASK OBJECTIVE

To develop and test algorithms for autonomous vision-based safe and precise landing on hazardous terrain

## MAJOR PRODUCTS

Algorithms for real-time decision making during landing based on surface reconstruction from passive imaging. Demonstration of algorithms in a realistic environment using an aerial testbed.

**PI:** Dr. Jim Montgomery (JPL)  
monty@robotics.jpl.nasa.gov  
(818) 393-1202 fax (818) 393-4085

**TEAM:** JPL, USC, Caltech

•YEAR	•DELIVERABLE
•FY01	•Onboard 3-D Surface Reconstruction
•FY02	•Hazard Detection and Avoidance
•FY03	•Target Tracking for Precision Landing

## NASA RELEVANCE

Enables missions that require a safe and precise landing capability, such as Mars Landers/Scouts, Comet Nucleus Sample Return, Europa Lander, Titan Organics Explorer

## ACCOMPLISHMENTS TO DATE

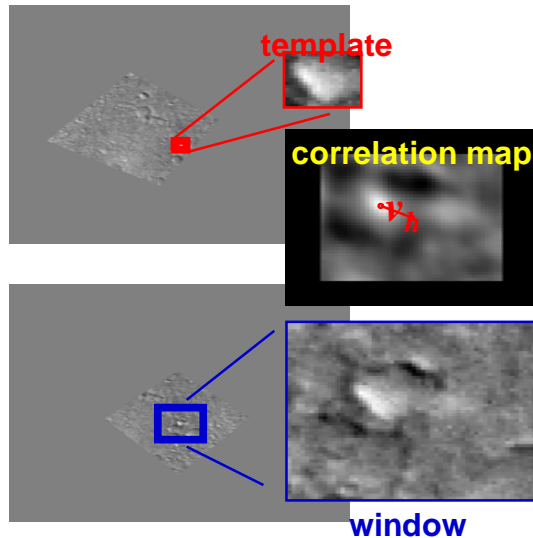
- FY01 & FY02 algorithms coded and tested off-line. Plan to demonstrate vision-based safe site selection with autonomous helicopter testbed by the end of FY02.
- Infused subset of our technology into MER mission
- Demonstrated autonomous flight with helicopter testbed
- Presented two papers at 2002 International Conference on Robotics and Automation



# Descent Image Motion Estimation Subsystem for MER (DIMES)

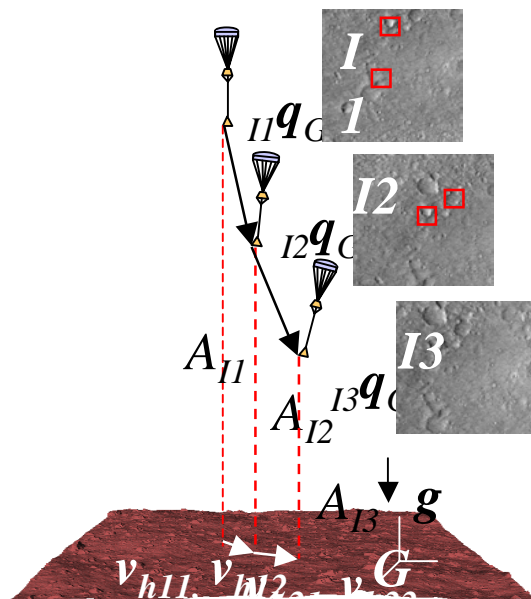


## APPROACH



**Problem:** Steady state winds during descent could impart a surface relative horizontal velocity to the Mars Exploration Rovers (MER) landing system, threatening lander safety.

**Solution:** estimate the horizontal velocity of the lander from images taken of the surface during terminal descent.



**Approach:** DIMES computes horizontal velocity, checks the answer for validity and passes a horizontal velocity correction to the Transverse Impulse Rocket Subsystem (TIRS). TIRS uses the horizontal velocity correction along with measurements of attitude to compute a TIRS rocket firing solution that reduces both RAD rocket and steady state wind induced horizontal velocity.

Jim Montgomery (JPL/Robotics), Larry Matthies (JPL/Robotics)  
Andrew Johnson (JPL/Robotics), Gaurav Sukhatme (USC), George Bekey (USC)



# Human-Centered Computing



Project Goal:

“Amplify and integrate human-automation performance.”

Technology  
Development

- Model-based Verification and Validation
- Decision Systems
- Multimodal Interfaces

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- Multimodal Interfaces

- Model-based Verification and Validation
- Decision Systems
- Multimodal Interfaces

Capabilities

- Distributed decision coordination systems

- Multi-modal interfaces for remote operations

- Seamless interfaces for mixed initiative teams

2002

2004

2007

20XX

20XX

20XX

Applications/  
Missions



Target  
Impact

Improvement  
in Science Return

Eliminate one shift  
Of operations

Mission  
Enabling



# ***Human Centered Computing***

## ***- Investment Areas -***



### **Model-based Design and Testing**

- “Mobile Agents” (Bill Clancey, NASA-Ames)
- “Work Practice Simulation Environment for Habitat Design and Scheduling” (Bill Clancey, NASA-Ames)
- “Teamwork in Practice: Design for Collaboration in Mixed Human-Robotic Teams” (Jeff Bradshaw, UWF IHMC)
- “Approaches to Human Centered Software Development” (Nancy Leveson, MIT)
- “Simulating Learning of Complex, Dynamic Tasks” (John Anderson, CMU)

### **Decision Systems**

- “Decision Systems for Launch and Range Operations” (Roger Remington, NASA-Ames; Jorge Bardina, NASA-Ames)
- “Human Centered Intelligent Systems for Mission Operations” (Jane Malin, NASA-JSC)
- “Human Centered Intelligent Flight Surgeon Console” (Jiajie Zhang, University of Texas Houston Medical Center)
- “Distributed Crew Interaction with Advanced Life Support Control Systems” (Debra Schreckenghost, Metrica/JSC)
- “Filtering Information in Complex Temporal Domains” (Pat Langley, ISLE)
- “MER HCC” (Jay Trimble, NASA-Ames)



### **Multimodal Interfaces**

- “Robust Speech Recognition Using Dynamic Synapse Neural Networks” (Ted Berger, USC)
- “Harnessing Speech Prosody for Robust Human-Computer Interaction” (Elizabeth Shriberg, SRI)
- “Multi-Media Human Computer Interfaces for Mission-Critical Systems” (Hamid Kohen, JPL)
- “Causal Reasoning” (Steve Sloman, Brown University)
- “Integrated Intelligent Support for Knowledge Capture, Refinement, and Sharing” (David Leake, University of Indiana)



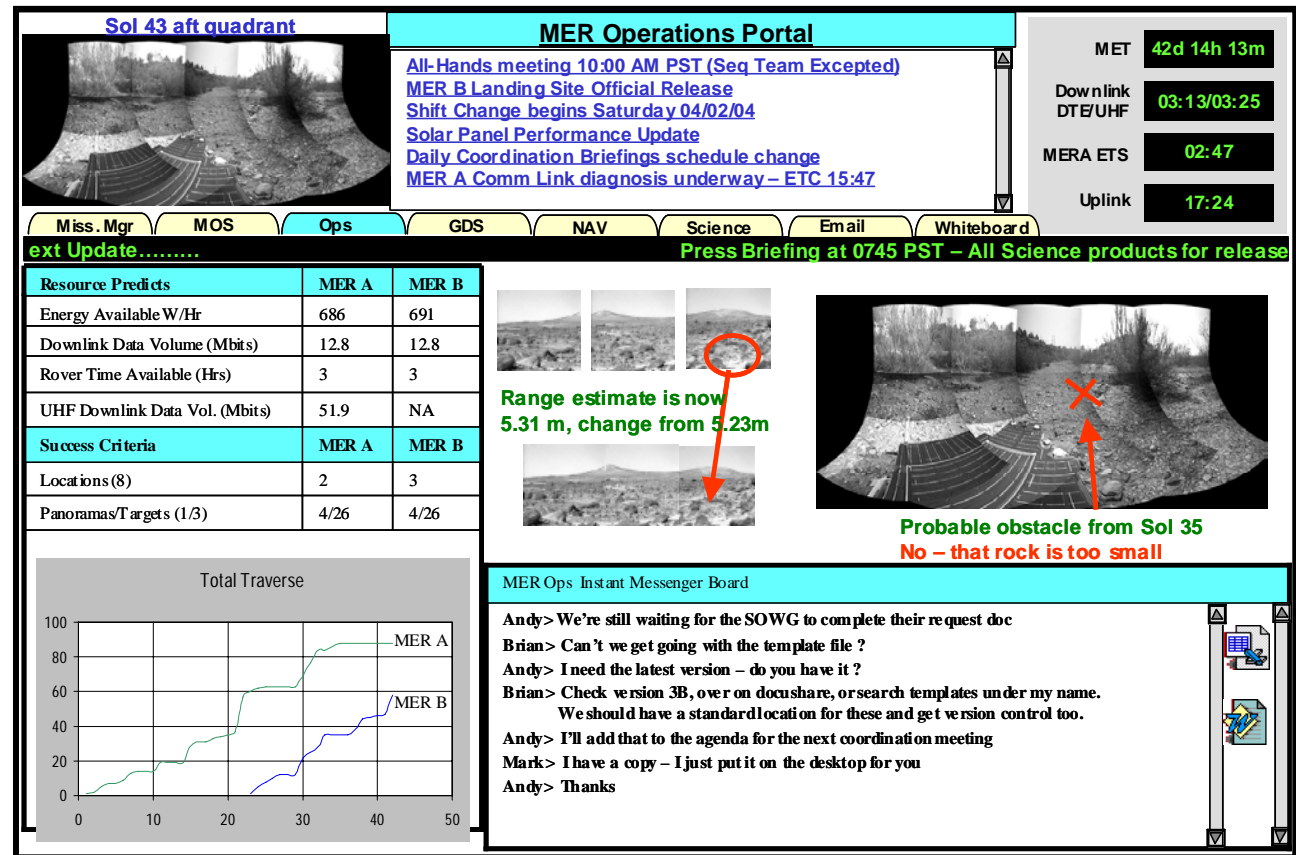


# MER Collaborative Information Portal



MER CIP is a flexible and adaptable information portal, co-designed by MER mission team, integrated, deployed, and evaluated during mission operations.

MER CIP can flexibly integrate a variety of information for timely presentation and flexible communication among ops team members.



**Result:** A useful tool for the MER mission; design foundation and feasibility demonstration for multi-mission data integration, schedule management, and distributed operations.



# ***MERBoard for Science Team Ops Planning***



**Combined COTS technology with NASA, JPL, IBM, and CMU design and software engineering expertise to deliver a MER science planning tool**

**Shown:** MERBoard used by MER science team in ops planning

**Output:** Graphically oriented planning tool that is easy to use under the real-time pressures of mission operations, but also enables more systematic and extensive archiving and retrieval of plan-rationales and associated documents.



**Outcome:** 1-2 orders of magnitude improvement in on-line documentation, including flexible storage and retrieval of annotated graphics, during Science Operations Working Group (SOWG) long-range and tactical planning. Key technology for future distributed mission operations.

**Beneficiaries:** MER, MSL; other NASA applications are being explored.



# Intelligent Data Understanding



## Project Goal:

**“Develop automated methods to discover and determine the *causation* of novel features in NASA’s large distributed science and engineering datasets.”**

### Technology Development

- Data Mining
- Knowledge Discovery, Understanding and Analysis
- Machine Learning for Decisions and Actions

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### Capabilities

- Spatio-temporal data mining and event prediction

- Spatio-temporal data mining, automated model discovery with multisensor fusion

- Automated hypotheses Generation from large databases



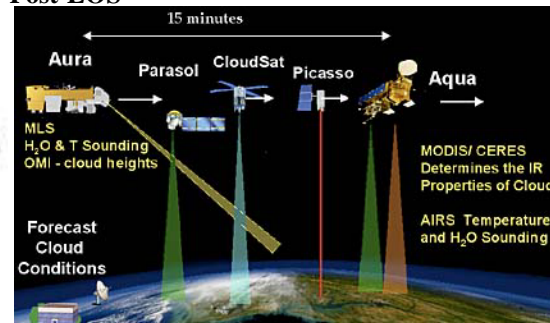
### Applications/ Missions



Terra

Enabling  
Ecosystem forecasting

#### Post-EOS



Mission  
Enabling

Target  
Impact



# ***Intelligent Systems***

## ***Intelligent Data Understanding***

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### **Investment Areas (with selected tasks):**

- **Data Mining**

- > **Spatial statistics and forecasting for Earth Science data** (Morris-RIACS, Smelyanskiy-ARC)
- > **Text Understanding** (Coughlan-ARC)
- ➡ > **Discovery of Changes from the Global Carbon Cycle and Climate System Using Data Mining** (Vipin Kumar-Univ. of Minnesota)

- **Knowledge Discovery, Understanding and Analysis**

- > **Automated data management** (Golden-ARC)
- > **Framework for understanding non-linear data with missing elements** (Wheeler-ARC)
- > **Mind's eye: Knowledge discovery process capture** (Yamasaki-ARC)
- > **Knowledge discovery support system** (Moljesness-JPL)
- > **Data fusion visualization, and condition monitoring of complex systems** (Shaw/Hall-Penn St.)

- **Machine Learning for Decisions and Actions**

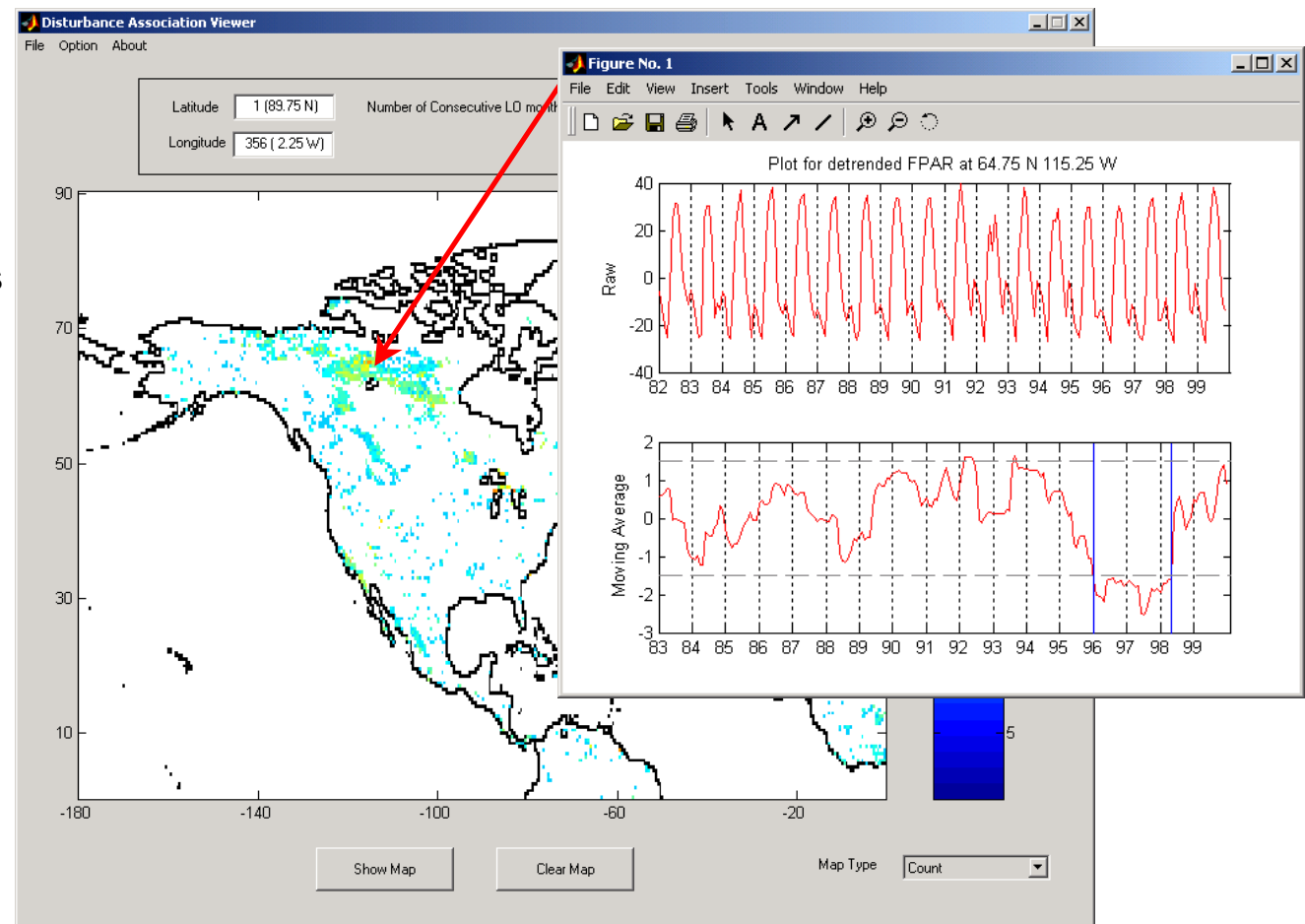
- > **Data-model fusion** (Thompson-ARC)
- > **Model-based, data-driven adaptive failure prediction** (Leen-OGI)
- > **Machine Learning for Earth Science Modeling** (Schwabacher-ARC)



# Automated Feature Extraction

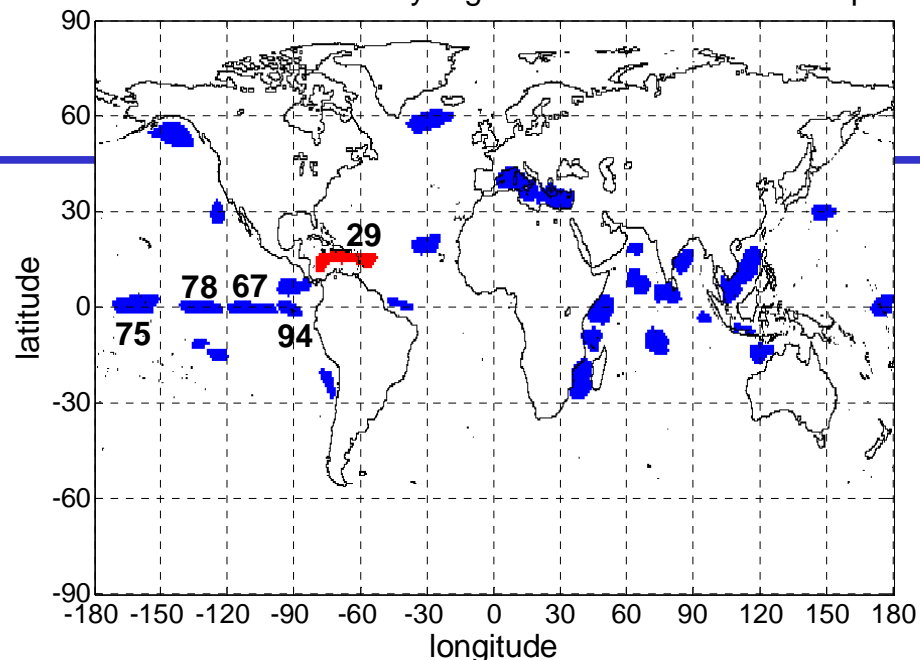


Time series plots of detrended monthly fraction photosynthetic active radiation (FPAR) values from the AVHRR sensor 1982 to 1999; top panel is original (raw) FPAR values in units of percent, and side panel is the deseasonalized FPAR anomalies in units of standard deviation from the 12-month moving average. Heavy vertical lines show the longest consecutive period of anomalously low FPAR values indicating vegetation disturbance and alterations carbon cycle (e.g. fire, logging and etc.)

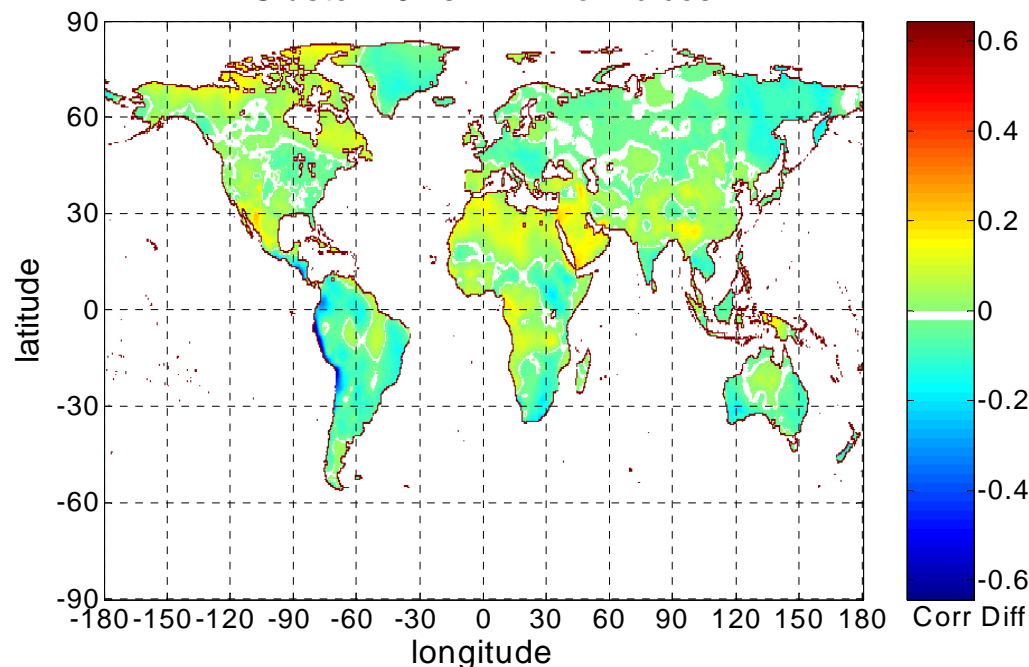




SST Clusters With Relatively High Correlation to Land Temperature



Cluster 29 vs. El Nino Indices



## Discovering Novel Features

A novel Shared Nearest Neighbor (SNN) clustering technique identifies regions of uniform satellite derived sea surface temperature (SST) data.

The bottom figure shows the difference in correlation to land temperature between a new candidate climate index (cluster 29) and the El Niño indices (clusters 75, 78, 67 & 94).

Areas in yellow to red indicate where cluster 29 has higher correlation (predictive power) than the El Niño indices.







- **60 University Participants**
- **Mid-TRL Programs:**
  - **Engineering for Complex Systems (ECS)**
  - **Mars Technology Program (MTP)**
  - **Astrobiology Science and Technology for Exploring the Planets (ASTEP)**
  - **New Millennium Program**
- **Government Agencies**
  - **DARPA**
  - **NSF**
  - **ONR**

